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The relationship between joint attention and theory of mind in neurotypical adults

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A B S T R A C T

Joint attention (JA) is hypothesized to have a close relationship with developing theory of mind (ToM) capabilities. We tested the co-occurrence of ToM and JA in social interactions between adults with no reported history of psychiatric illness or neurodevelopmental disorders. Participants engaged in an experimental task that encouraged nonverbal communication, including JA, and also ToM activity. We adapted an in-lab variant of experience sampling methods (Bryant et al., 2013) to measure ToM during JA based on participants' subjective reports of their thoughts while performing the task. This experiment successfully elicited instances of JA in 17/20 dyads. We compared participants' thought contents during episodes of JA and non-JA. Our results suggest that, in adults, JA and ToM may occur independently.

1. Introduction

Joint attention (JA) can be defined as the coordination of orienting between two people toward an object (Emery, Lorincz, Perrett, Oram, & Baker, 1997; Kristen, Sodian, Thoermer, & Perst, 2011; Moore & Dunham, 1995; Mundy & Newell, 2007; Scaife & Bruner, 1975). JA solidifies between 6 and 18 months of age in typically developing children and can be split into two main phases: initiation of joint attention (IJA) and response to joint attention (RJA) (Bruinsma, Koegel, & Koegel, 2004; Mundy et al., 2007). For example, a parent may initiate JA by pointing to an object, and their child may respond by shifting their gaze to follow the parent's point.

While JA is defined in terms of *observable human behavior*, theory of mind (ToM) involves the attribution of *unobservable mental states* (Malle & Knobe, 1997; Povinelli & Vonk, 2004). People capable of deploying ToM have the ability to think and reason about their own or another person's mental states, which include thoughts, beliefs, intentions, and/or desires (Malle, 2005, 2013; Premack & Woodruff, 1978; Wellman, Cross, & Watson, 2001).

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Several lines of research have led to four main hypothesized relationships between ToM and JA across human development. First, the emergence of JA skills may scaffold the later consolidation of ToM in typically developing children (Charman et al., 2000; Kristen et al., 2011; Moore & Dunham, 1995; Nelson, Adamson, & Bakeman, 2008; Roeyers, Van Oost, & Bothuyne, 1998). This conjecture follows a parallel premise in evolutionary and comparative psychology: JA may have been necessary for the eventual evolution of ToM in humans (Malle, 2002). JA behaviors have been experimentally observed in non-human animals, including chimpanzees (Povinelli & Eddy, 1996, 1997; Povinelli, Theall, Reaux, & Dunphy-Lelii, 2003; Tomasello, Hare, & Agnetta, 1999; Watts, 2002), other primates (Tomasello, Call, & Hare, 1998), ungulates (Kaminski, Riedel, Call, & Tomasello, 2005), and various bird species (Bugnyar, Stowe, & Heinrich, 2004; Loretto, Schloegl, & Bugnyar, 2010; Schoegl, Kotrschal, & Bugnyar, 2007). Although we believe there is no compelling evidence for ToM in non-human animals (Penn & Povinelli, 2007; Povinelli & Giambrone, 1999; Povinelli & Vonk, 2004), this is controversial, with many, if not most, groups in disagreement (Krupenye, Kano, Hirata, Call, & Tomasello, 2016; Tomasello & Call, 2006; Tomasello, Call, & Hare, 2003a,b).

Second, and contrary to the first hypothesis, some investigators have argued that the presence of ToM, or ToM-like behaviors, may be necessary in order to drive the development of JA (Tomasello, 1995; Tomasello, Carpenter, Call, Behne, & Moll, 2005). This would imply that ToM takes developmental primacy over JA.

Third, regardless of primacy in early typical development, JA and ToM are often thought to co-occur (Tomasello, Carpenter, & Liszkowski, 2007). According to this view, when one person orients another person to an object, or one responds to such an invitation, one or both partners are necessarily thinking about their own or the other's mental states. For example, the aforementioned orienting event might involve a person wanting the other to *share the experience* of watching an interesting video, or a child wondering what their parent *thinks* about a toy (see also Moore & Dunham, 1995).

Fourth, and finally, at an undefined point in development, JA and ToM may not systematically co-occur, because of the complex evolutionary relationship between the two systems (see Povinelli & Giambrone, 1999).[2] In this context, it is worth noting that few researchers have attempted to measure ToM occurrences during social interaction, and while some have found that overt ToM processes may be relatively uncommon during social interactions among adults (Bryant, Coffey, Povinelli, & Pruett, 2013), other studies found that such processes make up about one third of the thoughts about an interaction partner (Malle & Pearce, 2001). Most important, little research has attempted to quantify the co-occurrence of JA behaviors and ToM processes, and their relationship therefore remains poorly understood and experimentally underexplored.

Impaired JA is a primary, characteristic feature of Autism Spectrum Disorder (ASD) (Bruinsma et al., 2004), which may contribute to differences in language development and social behavior in individuals with ASD (Volkmar, Lord, Bailey, Schultz, & Klin, 2004). Children with ASD often also demonstrate lowered ToM capabilities (Baron-Cohen, 2000; Volkmar et al., 2004). Understanding better the continuities or discontinuities for the typical relationship between JA and ToM might, therefore, inform the refinement of effective joint attention-based interventions for individuals with ASD (Kasari, Freeman, & Paparella, 2006; Kasari, Gulsrud, Freeman, Paparella, & Hellemann, 2012).

Therefore, with this study, we aimed to (1) test the widely held assumption that ToM and JA naturally or normally co-occur, working with a sample of neurotypical adult humans who could give subjective reports of their thoughts, and (2) to establish methods that could, in the future, be adapted to test aspects of the third major aforementioned hypothesis in typically and atypically developing children. By directly testing for the association between operationally-defined occurrences of ToM and JA, we were able to measure the relative frequencies of mental state attributions during JA as compared to non-JA behaviors and, consequently, begin to answer the question of whether thinking about another adult's mental states is necessary for participation in JA.

2. Materials and methods

2.1. Participants

We recruited study participants through Washington University Volunteers for Health and word of mouth. Participants included 40 adults, aged 18–35 (mean age = 24.1, *SD* = 3.7), with no reported history of neuropsychiatric disorders and no family history of Autism Spectrum Disorder (ASD) or Attention-Deficit/Hyperactivity Disorder (ADHD). We compensated participants based on the length of their participation. The study was approved by the Washington University Human Research Protection Office.

2.2. Setup and procedure

Participants were scheduled to complete the experiment in pairs. After both individuals arrived, we brought them to a waiting room in our lab. We obtained informed consent from each participant separately.

[2] One account of such an evolutionary dissociation between ToM and JA is the reinterpretation hypothesis (see Povinelli & Giambrone, 1999). This model suggests that the evolution of complex social behaviors was not initially caused or accompanied by the evolution of ToM. Rather, the human ability to reinterpret behavior in terms of mental states evolved uniquely in the human lineage and in a way that did not initially drastically alter the basic social behaviors themselves.

Next, we brought them back together, gave them instructional packets, and explained the experimental procedure while they followed along (see Appendix A for complete instructions). We told participants that they would be working on a task in a room designated and equipped for the experiment. We explained that the experimental room was outfitted with a home-security system, which would allow us to monitor and communicate with them from a remote control room as they worked on the task. This system was comprised of eight cameras (3.6 mm, ~53.1° viewable horizontal angle) and a HIPAA-secure Skype connection between a hidden MacBook Pro (Windows 7 32-bit, Intel Core 2 Duo 2.2 GHz, 2 GB RAM) and a PC (XP Pro 32-bit, Pentium M 2.66 GHz, 2 GB RAM) that was located in our control room. This setup allowed us to (1) conduct live coding of the participants' behavior and (2) give them instructions throughout the task via the Skype connection.

We told the participants that there would be a poster containing ten pictures on the wall of the experimental room and that we had "hidden" nine of the displayed pictures among other photos on partitions that were set up throughout the room. We then explained that it was their task to determine which one of the ten images was not displayed elsewhere in the room. Participants were told they could not speak to or touch each other, or any pieces of the display, during the experiment; but they were free to "interact in any other way that you please." They were given nine minutes to complete the task.

Finally, we explained that we would periodically interrupt them (via Skype) by asking them to complete questionnaires, which were numbered, in order, over the course of the experiment. We asked them to complete the questionnaires in no longer than 60 seconds each, to complete them in the correct order, and to complete them independently, without interacting with their co-participants.

We then gave participants their own experimental questionnaires. In order to keep the participants' hands free for the majority of the experiment, each set of questionnaires, along with a pen, was placed inside a color-coded badge to be worn with a lanyard around their neck. We explained that, through the questionnaires, we would be asking them to report on their thoughts and actions immediately preceding each interruption (see more detail below). We let them know we would be asking about "mental states" and "actions" in multiple-choice questions, and we gave them definitions and examples of each (which can be found in Appendix A of Bryant et al. (2013)). Once participants understood how to fill out their questionnaires, they were given examples of the kinds of photos they would be looking for during the task (various animals, food, and everyday objects). Before entering the experimental room, participants underwent two practice rounds of the experimental task with a sample image in our lab's waiting room.

At the conclusion of the experiment, we debriefed each pair of participants by asking a series of questions. We showed participants each picture they were asked to find and asked each individual if they found it, what they thought of it, and whether or not they worked with their partner to find it.

2.2.1. Thought-sampling protocol

Over the course of the experiment, we interrupted participants and prompted them to report their thoughts four times: during bouts of JA, during NJA, and at two predetermined, "random" time-points. (See coding protocol below for our definitions of JA and NJA). The "random" interruptions were designed to provide opportunities to code behavior and sample thought at two predetermined time points, regardless of whether JA was occurring at that time, or what the participants were doing. Compared to JA or NJA events, "random" events enabled the collection of data unrelated to the rater's judgment of whether JA was occurring in that moment. When each NJA, JA, or random event occurred, the timer was paused, and participants would hear, "Please stop, and fill out Questionnaire #1 (or 2, 3, or 4)." The time of each event, as well as who was initiating and who was responding during an episode of JA, was immediately recorded, and participants were given 60 seconds to complete their questionnaires. Participants were asked to answer questions about the thought occurring immediately before they were interrupted. The questionnaires were a modified, paper version of the thought-sampling questionnaire used by Bryant and colleagues in 2013 (Bryant et al., 2013).

During these events, participants categorized their thoughts as Action (A), Mental State (MS), or Neither/Miscellaneous (N). We defined MS thoughts as indicative of ToM deployment. If participants categorized their thoughts as A or MS, they also noted the direction of that thought (toward themselves or another person). Participants were also asked about the degree to which they were socializing at that moment ("Are you directly interacting with other people?"). Lastly, participants responded in free text form to two questions, "What are you doing?" and "What are you thinking about?" If no JA was observed over the course of the experiment, participants would only have completed three questionnaires each (an NJA event, and the two predetermined random moments).

2.2.2. Live-coding & reliability protocol

In order to reliably detect, record, and act upon the coupled behavioral interactions involving JA, we developed operational definitions for initiation of joint attention (IJA) and response to joint attention (RJA). We defined a participant's pointing to an object and looking at their partner as IJA (Fig. 1, left).[3] When a participant was observed to move their head in the direction of the other participant's pointing gesture during IJA, we coded their behavior as RJA (Fig. 1, right). An IJA event that did not result in RJA (e.g., one participant pointing to an object and looking at their partner, but without their partner following the gesture) was considered a Non-JA (NJA) event. When participants were individually looking at objects, moving about the

[3] Some episodes also involved the participant who pointed looking back at the object, but this was not required for the coding of an IJA event.

Fig. 1. Lab members demonstrate this experiment's operational definition of JA. The adult on the left initiates JA (IJA) by pointing out an image and looking back at the person on the right, who responds by following the pointing gesture (RJA).

experiment room, and/or clearly not engaging in behavior that acted to co-orient the other participant's gaze toward an object, this was also coded as Non-Joint Attention (NJA) behavior.

Raters were trained to recognize JA in the Communication and Symbolic Behavior Scales-Developmental Profile (CSBS-DP) videos (Wetherby & Prizant, 2002) and in the First Signs, Inc. ASD Video Glossary (Unpublished, First Signs, Inc.). We developed a testing sequence in which lab members JRP and SK acted as participants in a randomized sequence of events that blind raters had to live-code as NJA or JA, and, if JA, record who initiated and who responded. Two raters, SH and JS, averaged 99.1% and 96.4% accuracy in these tests, respectively, and achieved excellent interrater reliability (*Cohen's kappa* = 0.96).

2.3. Analyses

The relationship between ToM and JA was tested in two main analyses, one considering only participants' multiple-choice responses to the prompt "Categorize your thought," with the Mental State (MS) option indicating ToM. The other analysis was performed on the participants' free-text responses to the question, "What are you thinking?" (see Section 2.3.1., Free-Text, Consensus-Coded Responses, below). In both cases, we compared the distribution of thought types—Action (A), Mental State (MS), or Neither (N)—sampled during JA and NJA.

2.3.1. Free-text, consensus-coded responses

We analyzed free-text responses to the question "What are you thinking?" by re-coding them according to the protocol developed in our previous experience-sampling study (Bryant et al., 2013). In addition to the A, MS, or N categories, re-coded thoughts could also be labeled as "Indeterminate," "Why statement or question," or "No Thought." LKB and JRP resolved all discrepancies between their re-codings of participants' thoughts.

2.3.2. Independent and non-independent observations

First, we performed several one-way Pearson's chi-square tests of goodness-of-fit to examine the distributions of thought types reported following each event type (NJA, JA, or either of two "Random" events). We call these "independent observations" because separating reports by event type disaggregates the multiple responses that each participant contributed. With these analyses, we did not directly compare the distribution of A, MS, or N thought types between JA and NJA events to test whether ToM may be more likely to occur during JA. Instead, we aimed to examine the distribution of thought types themselves, looking to characterize how participants' responses are generally skewed before separating by and comparing across the presence of JA.

We then used two-way Pearson's chi-square tests of association to directly compare the proportions of A, MS, or N thoughts in the presence of JA or NJA. We call these "non-independent observations" because different responses from the same participants are pooled together across event types.

We first report participants' multiple-choice thought categorizations and consensus-coded responses as separate sets of independent observations, then multiple-choice and consensus-coded responses as separate sets of non-independent observations.

2.3.3. Validity checks

To explore how well and consistently our design prompted JA, we explored the frequency of observed JA in all experiments. We also checked whether our live-coded observations, at least loosely, matched participants' reports of whether they were interacting with each other. To determine whether the dyadic nature of the experiment may have influenced each participant's responses, we examined dis/similarities between questionnaire responses within each pair of participants by assigning two types of "agreement scores" to each dyad, defined by (1) the number of questionnaires on which they simultaneously reported the same thought category and (2) the number of questionnaires on which their free-text responses were consensus-coded into the same category. We also computed the raw percentages of both types of agreement for each dyad. Independent samples *t*-tests determined whether participants' agreement scores significantly differed from a test statistic representing what would be expected by chance, as well as whether agreement scores significantly differed between pairs of participants who were familiar with their partners before engaging in the experiment (seven dyads) and those who were not (thirteen dyads).

3. Results

3.1. Responses included in analyses

Forty participants were paired to complete twenty dyadic experiments. Each of these experiments was predicted to generate eight thought-sampling reports, from four previously-described interruptions, to yield a total of 160 reports. Seventeen of twenty dyads engaged in JA, resulting in a total of 154 responses for potential analyses. We chose not to exclude dyads who never engaged in JA from our main analyses, as they contributed only 18 of our 154 total reports, and their behavior contributes to the natural range of social activity observed in this study.

One report was excluded from multiple-choice analyses due to the participant's interpretation of our instructions.[4] Five answers to the question, "What are you thinking about?" could not be re-coded as Action (A), Mental State (MS), or Neither (N) thoughts and were excluded from analyses of consensus-coded thoughts.[5] Five participants' responses were excluded only from analyses that took thought direction into account.[6]

3.2. Validity checks

3.2.1. Frequency and temporal distribution of JA

This experiment elicited several instances of JA from most participating dyads—seventeen out of twenty. In addition to JA that was recorded immediately prior to thought-sampling events, we recorded all episodes of JA observed during each experiment (i.e., JA that was not coded in association with an experimental thought-sampling interruption). We recorded a total of 99 episodes of JA and an average of 4.95 (SD = 3.43) episodes per experiment. When we excluded the six participants who did not engage in JA, the remaining thirty-four participants averaged 5.82 episodes per experiment (SD = 2.92).

Although the majority of our participants engaged in several episodes of JA with their partners, as time went on during the experiment, the frequency significantly decreased. To understand the distribution of JA over time, we divided the nine-minute experiments into four quarters, each lasting two minutes and fifteen seconds, and we averaged the number of episodes of JA occurring within each quarter among each of the seventeen dyads who engaged in JA. During the first quarter, a sum of 60 and a mean of 3.53 JA episodes were observed per dyad (SD = 2.35); during the second quarter, we observed 34 total episodes with a mean of 2.00 (SD = 1.97); and, during the third quarter, five episodes were observed with a mean of 0.29 (SD = 0.59). Our experiment did not elicit JA between any participants during the last quarter of the experiment. A repeated measures analysis of variance indicated that JA episodes significantly decreased as the experiment went on (F = 18.03, df = 1.77,[7] $p < 0.001$).

3.2.2. JA live-coding

We tested the validity of our live-coded events by comparing them to participants' responses, and the results suggest that our procedure to recognize and record JA detected what most participants would consider as social interaction. On 84.1% of questionnaires sampled immediately after JA, participants indicated that they were interacting with each other on their questionnaires ($\chi 2$ = 28.64, df = 1, $p < 0.001$). The remaining 15.9% consisted of seven questionnaires, two of which came from the same participant, and six of which came from participants responding to the other participant's bid for JA (RJA), as opposed to initiating JA (IJA). Two of these questionnaires, including the single IJA questionnaire, came from participants in the same dyad at the same time.

3.2.3. Agreement between participants' thought types

In order to determine if the dyadic format of the experiment may have influenced the independence of participants' thought categorizations, we computed the aforementioned agreement scores, as well as percentages of reports on which

[4] This participant chose both Action (A) and Mental State (MS) to categorize one of their thoughts.

[5] One questionnaire was re-coded as "No thought," two were re-coded as "Indeterminate," and two were re-coded as "Why" thoughts. Two of these questionnaires – one containing a "Why" thought and one containing "No thought" – were collected from the same participant.

[6] When participants categorized their thoughts as A or MS, they were asked to note whether their thoughts were directed toward someone else or toward themselves. Three participants returned questionnaires with both options circled, and two participants noted the direction of their thoughts after categorizing their thoughts as Neither (N), not A or MS.

[7] Greenhouse-Geisser corrected.

Table 1
Distribution of contents of thoughts (multiple-choice measure): actions, mental states, or neither.

Event		A	MS	N	χ^2	*df*	*p*
	Total	15	18	1	14.53	2	0.001
JA	IJA	8	9	0	8.59	2	0.014
	RJA	7	9	1	6.12	2	0.047
NJA	Total	12	21	6	8.77	2	0.012
Random event 1	Total	15	12	5	4.94	2	0.085
Random event 2	Total	11	21	6	9.21	2	0.010

IJA = Initiating Joint Attention; RJA = Responding to Joint Attention; NJA = Non-Joint Attention; A = Action; MS = Mental State; N = Neither; df = degrees of freedom.

both participants simultaneously indicated the same thought category and percentages of paired reports that were consensus-coded within the same A, MS, or N thought category. The following analyses show that paired participants chose the same multiple-choice thought category significantly more often than expected, while the amount of agreement between their free-text responses suggests their actual thought content to be more independent. We also determined that whether participants in each dyad knew each other before completing the experiment did not affect their mean multiple-choice or consensus-coded agreement scores. Interestingly, however, participants were more likely to choose the same multiple-choice answer immediately after we observed them engaging in JA, compared to when they were not engaging in JA. This significance is not observed for consensus-coded thought categories.

Participants chose the same thought category as their partners 50.0% of the time ($SD = 28.613$), ranging from 0% (2 dyads) to 100% (2 dyads). Overall, participants in the seventeen dyads who engaged in JA[8] chose the same multiple-choice thought category significantly more often than what would be expected by chance, $t(16) = 2.922$, $p = 0.01$, but participants who knew each other prior to the experiment were not more likely to select the same thought category, $t(10.18)$[9] $= -0.504$, $p = 0.625$. This suggests that familiarity does not influence multiple-choice agreement scores. Participants' free-text thought reports were re-coded into the same category as their partner's 33.8% of the time ($SD = 19.771$), ranging from 0% (2 dyads) to 75% (2 dyads). Re-coded agreement scores did not differ from those expected by chance, $t(16) = 0.11$, $p = 0.914$. Participants who knew each other prior to the experiment were not more likely to have their thoughts re-coded into the same category, $t(9.32)$[10] $= -1.005$, $p = 0.340$. A paired-sample t-test found a trend-level difference between multiple-choice and consensus-coded agreement scores, $t(19) = 2.04$, $p = 0.055$.

A Pearson's chi-square test showed a significant association between the presence of JA and participants' agreement on multiple-choice thought categorizations ($\chi2 = 4.58$, $df = 1$, $p = 0.032$). Participants reported the same thought category on 63.6% of questionnaires sampled immediately after JA was observed. However, we found no significant association between the presence of JA and multiple-choice agreement when we removed questionnaires produced by the three dyads who engaged in no JA at all from the analyses: ($\chi^2 = 3.41$, $df = 1$, $p = 0.065$). We found no significant association in consensus-coded results for all twenty dyads ($\chi^2 = 0.581$, $df = 1$, $p = 0.446$) or for the seventeen dyads that engaged in JA at least once ($\chi^2 = 0.624$, $df = 1$, $p = 0.430$).

3.3. Independent observations

Before taking into account differences between thought type distributions across JA and NJA (analyses involving non-independent observations), we examined all independent multiple-choice and consensus-coded thought categorizations, broken down by event type (JA, NJA, and two random events) in order to get a better idea of the distribution of thought types categorized in the different conditions of this experiment. Thoughts sampled after JA were further broken down into IJA and RJA thoughts. Excluding one participant's selection of both A and MS and the unreliably small sample of ten thoughts sampled after JA during random events, these thoughts were grouped by event type in Tables 1 and 2, with chi-square, degrees of freedom, and p-values reported for each goodness-of-fit test.

Overall, the series of tests depicted in Tables 1 and 2 suggests that A, MS, and N thoughts were more evenly distributed when consensus-coded from participants' free-text responses than when selected by participants themselves. A Pearson's chi-square test of goodness-of-fit determined significant deviation from an equal distribution of multiple-choice categorizations immediately following targeted JA events, with MS as the most popular multiple-choice category. This pattern held when responses from participants initiating JA (IJA) and responding to JA (RJA) were examined separately. Similarly, the distributions of thought categorizations immediately following NJA and the second random event also significantly deviated from equal distributions. No significant patterns emerged from multiple-choice thoughts during the first random event,

[8] The three dyads who did not engage in JA were excluded from this analysis, as the test statistic—representing the agreement score expected by chance—differs according to how many questionnaires each dyad completed.

[9] Equal variances not assumed.

[10] Equal variances not assumed.

Table 2
Distribution of contents of thoughts (consensus-coded method): actions, mental states, or neither.

Event		A	MS	N	χ^2	*df*	*p*
	Total	11	10	12	0.18	2	0.913
JA	IJA	5	6	6	0.12	2	0.943
	RJA	6	4	6	0.50	2	0.779
NJA	Total	13	10	16	1.39	2	0.500
Random event 1	Total	13	6	12	2.77	2	0.250
Random event 2	Total	9	13	15	1.51	2	0.469

IJA = Initiating Joint Attention; RJA = Responding to Joint Attention; NJA = Non-Joint Attention; A = Action; MS = Mental State; N = Neither; df = degrees of freedom.

although participants, again, tended not to classify their thoughts as N. We determined no significant deviation from an equal distribution of consensus-coded thought types immediately following JA, NJA, or either of the random events (Table 2).

3.4. Non-independent observations

To test our main hypotheses, we then pooled multiple-choice (Table 3) and consensus-coded (Table 4) responses across all event types in order to examine their overall distribution, as well as to directly compare their distributions according to the presence or absence of JA, and whether these distributions changed according to the direction of participants' thoughts. In contrast to our reporting of all independent observations, these non-independent responses now also include those reported immediately following the observation of JA during a Random event. Pearson's chi-square tests of goodness-of-fit described the overall distribution of thought types pooled across events, as reflected in the uppermost rows of Tables 3 and 4. Pearson's chi-square tests of independence determined whether JA or NJA were significantly associated with patterns of thought types overall. These observations were further divided into thoughts that participants indicated as directed "toward myself" or "toward another person," to investigate whether the direction of participants' thoughts affected the potential relationship between JA and ToM.

Goodness-of-fit tests summarized in the first rows of Tables 3 and 4 mirror the results of analyses of independent observations, showing, again, differences in the distribution of multiple-choice compared to consensus-coded thoughts. When multiple-choice thought categorizations are pooled together, participants favor the MS option (Table 3, top row). When these multiple-choice observations were split according to the presence or absence of JA, Pearson's chi-square test

Table 3
Distribution of contents of thoughts (multiple-choice measure): actions, mental states, or neither, compared across JA and NJA.

		A	MS	N	χ^2	*df*	*p*
	Total	57	78	18	36.53	2	<0.001
All thoughts	JA	19	24	1	5.47	2	0.065
	NJA	38	54	17			
JA	"Toward Myself	4	14	–	5.51	1	0.019
	/Another Person"	13	17	–			
NJA	"Toward Myself	25	36	–	0.09	1	0.762
	/Another Person"	12	15	–			

IJA = Initiating Joint Attention; RJA = Responding to Joint Attention; NJA = Non-Joint Attention; A = Action; MS = Mental State; N = Neither; df = degrees of freedom.

Table 4
Distribution of contents of thoughts (consensus-coded method): actions, mental states, or neither, compared across JA and NJA.

		A	MS	N	χ^2	*df*	*p*
	Total	48	42	59	2.99	2	0.224
	JA	13	13	16	0.22	2	0.895
All thoughts	NJA	35	29	43			
JA	"Toward Myself	4	7	7	1.10	2	0.580
	/Another Person"	8	6	8			
NJA	"Toward Myself	20	19	22	0.56	2	0.756
	/Another Person"	11	9	8			

IJA = Initiating Joint Attention; RJA = Responding to Joint Attention; NJA = Non-Joint Attention; A = Action; MS = Mental State; N = Neither; df = degrees of freedom.

of independence showed a trend-level increase in A and MS thoughts, relative to N thoughts, reported immediately following JA compared to NJA.

In order to determine whether self- and other-directed thoughts may have been distributed differently according to participants' multiple-choice thought categorizations, we also separated thoughts during JA and NJA according to the self-reported direction of those thoughts. Pearson's chi-square test of independence showed a significant pattern, with a numerical decrease in self-directed Action thoughts compared to other-directed Action thoughts and both self- and other-directed MS thoughts during JA. Self- and other-directed thoughts did not significantly vary across thought type during NJA.

Again, comparing multiple-choice and consensus-coded responses suggests that consensus-coded responses are more evenly distributed across thought types. In contrast to the multiple-choice results, a goodness-of-fit test of consensus-coded, free-text responses showed no significant deviation from an equal distribution of thought types. Pearson's chi-square test of independence showed no significant association between any consensus-coded thought category and the presence of JA. We also split consensus-coded thoughts into self- and other-directed thoughts, with neither category showing significantly different patterns of A, MS, or N thoughts, during JA or NJA.

4. Discussion

We aimed to determine whether thinking about another adult's mental states (Theory of Mind, ToM) is necessary for participation in Joint Attention (JA). Our experimental design successfully prompted JA in seventeen out of twenty dyads of participants, although the frequency of observed JA episodes significantly decreased over time. Additionally, we found a significant association between the presence of JA and the affirmative answer to "Are you directly interacting with other people?" with participants indicating "Yes" during 84% of the events we coded as JA. It is important to note that six out of seven responses comprising the remaining 16% came from participants receiving the other participants' bid for JA. It may be easier for participants initiating JA to recognize their "request for attention" (Meindl & Cannella-Malone, 2011) than for participants responding to JA to recognize their receiving role in a social process that may occur automatically (Povinelli & Eddy, 1996).

The differences between multiple-choice and consensus-coded responses in our main analyses of independent and non-independent distributions of thought types suggest that participants were more likely to classify their thoughts as Mental State (MS) and less as N, whereas consensus-coded, free-text responses were more evenly distributed across the three categories. These results—obtained from an in-lab, dyadic experiment—contrast with those of our out-of-lab experience sampling study (Bryant et al., 2013), in which each subject individually completed electronic versions of the same questionnaire used in this study, and multiple-choice frequencies of A, MS, and N thoughts were more evenly distributed. There may be aspects of our dyadic and in-lab experience sampling—perhaps including the generation of JA— that caused participants to overestimate their own mental state attributions in their multiple-choice responses.

Our main analyses show that JA and ToM, as we define and sample them, occur independently. In our analyses of multiple-choice responses, we observed a trend-level, non-significant increase in A and MS thoughts, relative to N thoughts, reported immediately following JA compared to NJA. Again, however, consensus-coded A, MS, and N thoughts were more evenly distributed, and, importantly, this pattern holds across JA and NJA, with neither condition showing a significantly proportional increase in mental state attributions. The trend-level association between the presence of JA and the proportion of thoughts that participants categorized as MS supports a more traditional developmental psychological view of ToM occurring during JA (Moore & Dunham, 1995). The increase in participants' multiple-choice agreement scores immediately following JA may also be related; if participants were more likely to agree with each other on their own thought categorization immediately following JA, and the most common thought category reported after JA was MS, then perhaps JA fosters, involves, or overlaps in time with some aspect of social connectedness driving mental state attributions. However, the definitive results of our analyses of consensus-coded, free-text responses suggest that ToM and JA do not co-occur. These align with our previous findings that more mental state attributions occur when participants are not interacting with other people (Bryant et al., 2013). We had also previously found that participants were more likely to direct MS attributions toward themselves than toward other people (Bryant et al., 2013). In the present study, we observed this trend numerically in multiple-choice and consensus-coded results collected immediately after NJA.

The lack of a tight association between ToM and JA in adult humans can be considered from an evolutionary perspective by asking whether ToM and JA co-evolved because of a causal dependency between them. The answer to this question could cast important light on potential dissociations of these phenomena in both typical and atypical human development. For example, it is well-established non-human primates can engage in JA as defined in the present study (Povinelli & Eddy, 1996, 1997; Povinelli et al., 2003; Tomasello et al., 1998; Tomasello et al., 1999; Watts, 2002). If it were also true that non-human primates are not capable of ToM, then ToM cannot be necessary for JA (Penn, Holyoak, & Povinelli, 2008; Penn & Povinelli, 2007; Povinelli & Vonk, 2004; see Povinelli & Giambrone, 1999 for a detailed account of why JA and ToM could have separate evolutionarily histories). Our present experimental work would then be understood as reflecting the distinct evolutionary histories of these phenomena: while JA might in some contexts be modulated by ToM in typical adult humans, no strict causal dependency is necessary (Povinelli & Giambrone, 1999).

If the canonical assumption that ToM and JA must co-occur is incorrect, this has important implications for future research aimed at investigating the underlying structure and determinants of both. For example, are the developmental pathways for JA and ToM initially independent, only to become loosely entangled later? Moreover, the precise relationship between JA and ToM has clinical implications for autism spectrum disorder (ASD), which is strongly associated with the atypical expression of both JA and ToM. However, it is currently unknown if such atypical expressions reflect impairments of a single, core developmental pathway or impairments in one or more independent pathways. It is possible, and perhaps likely, that ASD reflects a heterogeneous group of early impairments that manifest themselves as a cluster or spectrum because of broadly similar impacts on behavioral, and then later, cognitive organization (Pruett & Povinelli, 2016). Increased knowledge about maturational changes in the relationships between JA and ToM in typical development could inform the direction of future research on evidence-based interventions for ASD.

4.1. Limitations

Asking people to think about and report on their thoughts poses significant limitations, including imprecision and the potential for confusion. Applying experience-sampling techniques to detecting ToM, too, poses its own challenge: our study depends on the assumption that ToM activity is at least partially accessible to conscious thought and detectable in reports of these thoughts. However, even if neurotypical adults may not naturally and/or consciously recognize many of their mental state attributions as such, their written thought reports can be classified by independent raters into mental state attributions and other contents of thought (Ericsson & Simon, 1980; Malle & Pearce, 2001). It is important to consider that we did not aim to detect or measure other, more implicit forms of mental activity described as ToM that could occur during JA. As an additional limitation, there is a possibility that it may have been easier for participants to quickly categorize their thoughts in response to multiple-choice questions than for them to articulate them in a free-text response in a way that was most amenable to our consensus-coding procedure.

Our operational definitions of IJA and RJA constrained the kinds of events we could code as JA (e.g., eye-gaze shifts without pointing were not visible to our cameras). Obtaining an accurate view of more subtle forms of IJA would have required more specialized equipment and, possibly, a much smaller, constrained space for the experiment. We wanted our laboratory setting to encourage the most naturalistic social experience possible, so we believe this is an acceptable compromise.

Finally, virtually all JA was captured in the first half of all experiments. It is possible that our design did not elicit JA over a sufficient period of time to detect an association with ToM. Additionally, although our task was designed to elicit nonverbal communication that we could objectively code as JA, it is also important to note that preventing participants from speaking to and touching each other, as per our instructions, posed a substantial difference from real-world communication and social interaction. The goal-directed nature of our JA-eliciting task, as well, may have restricted the types of JA we could observe in the laboratory by preventing more spontaneous and generative JA.

4.2. Future directions

Future experiments may do well to rely on free-text responses to the question "What are you thinking?" so as to avoid asking participants to undertake the perhaps difficult task of thought-categorization.

ToM may not be more likely to occur during JA than NJA episodes, but further experiments could determine whether MS attributions predict subsequent episodes of JA, or vice versa. Future experimental designs could enable examination of thought types at different time points before and immediately after JA episodes. By measuring ToM in a way that does not disrupt participants' social interactions, we may be able to provide a more naturalistic in-lab social setting, which could enable us to gather continuous data describing JA and ToM over time.

Neuroimaging experiments may help inform our understanding of the neural correlates of JA and ToM and whether or not they may be causally related. Few imaging studies have produced conclusive results elucidating the neural bases of dyadic social interactions, in large part due to the lack of availability of portable, noninvasive neuroimaging techniques. However, the use of fMRI currently facilitates an emerging collection of work on individual (Heyda, Green, Vander Wyk, Morris, & Pelfreh, 2010) and dyadic paradigms (Bilek et al., 2015; Koike et al., 2016) for the study of JA in real time. The continued development of High-Density Diffuse Optical Tomography (HD-DOT) as a method comparable to fMRI (Eggebrecht et al., 2012, 2014; Redcay et al., 2013) may offer further promise for future experiments collecting brain-based data while subjects participate in less constrained, more naturalistic dyadic social tasks.

Our study suggests that ToM is not associated with JA in typical adults who are nonverbally interacting with each other to accomplish a goal, but we do not address the potential developmental connections between JA and ToM. According to the first hypothesized relationship we reviewed, JA may be necessary for developing ToM capabilities (Charman et al., 2000; Kristen et al., 2011; Moore & Dunham, 1995; Nelson et al., 2008; Roeyers et al., 1998), but the apparent dissociation of ToM and JA in neurotypical adults suggests that they may become independent at some point during or after childhood. If ToM and JA are not significantly associated in adults, and if JA is a developmental precursor for ToM (or, if, as some investigators have argued, ToM may be required for the development of JA (Tomasello, 1995; Tomasello et al., 2005)) is there a developmental time point at which they are associated during social interactions? Adapting this study for similar experiments with children could elucidate this point and help determine if and at which points along the life course ToM and JA occur simultaneously in social interactions, as well as the developmental point at which they may dissociate.

5. Conclusion

Our results challenge the common assumption that theory of mind and joint attention are mutually dependent in adults. At least in a nonverbal task, the two processes did not systematically co-occur. Examining the relationship between social cognitive functions such as theory of mind and joint attention is important for our understanding of typical human development, and it may aid in developing and improving evidence-based interventions for ASD.

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Appendix A

A.1 Instructions

You will be paired with another participant; you will be assigned an identifying number, 1 or 2. You will spend approximately 15–20 min in an experiment room with your co-participant. If necessary, you may open the door and leave the room at any time. There is an audio connection so that I can hear you and you can hear me, in case of an emergency, and so you can hear my instructions. You will also notice that there are cameras in the room. You are not being recorded, but monitored. Both audio and visual streams are private and secure.

Here's what you are going to do: There's a poster with ten pictures in the room. You and your co-participant can work together to find them among the other pictures in the room. One of the pictures on the poster is missing. You have ten minutes to figure out which picture on the poster is not in the rest of the pictures in the room. Please don't touch the pictures or anything around them. You may not speak to or touch your partner, but you may interact in any other way that you please.

You will also be completing a series of four questionnaires while you find the pictures in the room. In order to keep your hands free for the majority of the experiment, I've placed your questionnaires in labeled badges. Put it on with the label facing outward. Each questionnaire should take no longer than 45 s to complete. Over the course of the experiment, I will be interrupting you and prompting you to complete each questionnaire in order. You must complete the four questionnaires by yourself (without assistance or input from anyone else). Please do not show your answers to your co-participant. Two of the questions require a short written response. Please be thorough in your responses; one to two sentences should be sufficient. Participation requires answering each question throughout this study. After you have viewed all of the pictures, I will ask you individually and together what you thought about each one. Before participating, please ensure that you can fulfill these requirements.

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